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| IALA Guideline |

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Systems and services for high-accuracy positioning and ranging

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# PURPOSE, SCOPE AND STRUCTURE OF DOCUMENT

## Purpose

Over the last decades, Global Navigation Satellite Systems (GNSS) became the primary mean for worldwide absolute position fixing in the maritime community. By using one of the first GNSS (GPS, GLONASS) it was possible to determine the horizontal position with an accuracy of several 10 meters. In the 1990s, GNSS augmentation systems such as IALA Beacon DGNSS [1,2] have been developed and established to provide correction data for GPS or GLONASS signals in the upper L-band. These services made it possible to meet the requirements on position accuracy and integrity for ship’s navigation in coastal areas. At present and under nominal conditions horizontal position accuracies (HPA) of few meters are achievable with operational GNSS, if dual-frequency signal processing techniques mitigate the influence of ionospheric propagation effects. The demand on systems and services for high-accurate positioning and ranging results from specific navigational manoeuvres (e.g. automatic docking) as well as specific nautical applications (e.g. automatic track control in critical areas, dynamic positioning, pilotage). The purpose of this document is to give guidance for deployment, installation and operation of maritime systems and services, which enable high-accuracy positioning or ranging in specific areas such as waterways, traffic separation schemes, traffic zones with limited manoeuvring space, ports and harbours, and highly frequented traffic areas with increased risks of collisions and groundings.

## Scope

The document provides state-of-the-art information for stakeholders, operators and end users of systems and services supporting high-accuracy positioning or ranging. In these Guidelines, the term “high-accuracy positioning and ranging” complies with accuracies at sub-meter level. The intended use of position data determines the demand on either absolute or relative position accuracies. For specific applications, it may be sufficient to determine the distance to obstacles or other traffic participants. Enhanced GNSS augmentation services as well as alternative and complementary localisation systems are suitable approaches for high accurate positioning and ranging. Systems and services for high-accuracy positioning and ranging are particularly needed in more demanding safety-critical situations and areas (where accuracies less than one meter is needed). Therefore, the guidelines should outline if and how the systems and services monitor the integrity of functions performed and data provided.

## Structure of document

In general, IMO’s performance standards often specify minimum requirements on systems, services and equipment. Because of this, solutions enabling high-accuracy positioning and ranging remain often undiscussed in current performance standards. Therefore, chapter 2 starts with a list of use cases and specific nautical applications to explain conditions under which an increased demand on accuracy of positioning becomes necessary. This approach is compliant to IMO Resolution A.915(22) providing the “Revised Maritime Policy and Requirements for a Future Global Navigation Satellite System (GNSS)” [4] and defining performance requirements in relation to specific navigational phases, nautical applications as well as diversity of maritime professions. Chapter 3 starts with a short summary of these existing performance specifications. The chapter discusses performance identifiers and levels under consideration of their relevance for system operation and utilization. For this purpose, a generalized scaling of all performance parameters are introduced. Chapter 4 gives an overview on technical systems and services supporting high-accuracy positioning and ranging. The annexes of the document serve the detailed description of single systems and services and provide the guidance needed for their deployment, installation, and operation. Further annexes are placeholders for future system and service solutions. Chapter 5 provides a template for the description of implementation and operation aspects captured in the annexes. The main document will conclude with the list of abbreviations and references. An additional appendix provides definition of terms used in these Guidelines.

# USE CASES

A lot of navigational application arises and may only be realised if appropriate systems and services enable a high accurate ranging and/or positioning. Navigational applications may be assistance functions supporting bridge teams with respect to situation surveying, evaluation and management. The partial or complete realisation of navigational tasks by system functions (e.g. docking) represents a more challenging type of navigational application. Assistance as well as system functions may be performed semi- or full-automatically. An increasing level of automatization reduces the potential influence of bridge teams to detect and compensate uncertainties, inaccuracies and malfunction in navigational systems and information. This implicates the necessity that the integrity of high accurate range and position also needs to be considered.

Table 1 summarizes use cases for high accurate ranging and positioning and describes the purpose of assistance or system functions.

1. Example use cases for high accurate positioning and ranging

|  |  |  |  |
| --- | --- | --- | --- |
| Use case | Purpose of assistance or system function | Ranging approach | Positioning approach |
| Docking | During docking it is necessary to prevent collision of ship’s hull with infrastructures. | Selective distance measurements to determine ship’s hull in relation to hydro-infrastructures  (R) | Position-based determination of attitude of ship hull in relation to the geo-referenced attitude of hydro-infrastructure  (P4R) |
| Locking | During entry and exit of the lock it is necessary to prevent collision of ship’s hull with the lock infrastructure. |
| Passing of narrow channels | During the passage of narrow channels it is necessary to prevent collision of ship’s hull with canal banks. |
| Turning | Turning manoeuvres of ships are necessary in port and harbours to arrive or depart the shipping berth.  Especially the turning of large-size vessels in areas with limited manoeuvring space makes it more difficult to avoid groundings or collisions with harbour infrastructure. | Selective distance measurements to determine ship’s hull in relation to available navigation space  (R4P) | Position-based determination of attitude of ship hull in relation to available (geo-referenced) navigation space  (P) |
| Passing of bridges | The size of bridge arches determines the available passage width (similar to passing of narrow channels) as well as the available clearance. Small sizes of bridge arches, varying water levels, and load-dependent ship depths has to be taken into account to avoid collisions of ship’s hull with bridges. |
| Passing of shallows | Varying water levels and load-dependent ship depths has to be taken into account to avoid groundings in times of maximum load or low tide. |

R: Ranging

P4R: Use results of positioning to determine distances (ranges)

R4P: Use of measured ranges to enable or support the determination of positions

P: Positioning

Table 2 includes an initial list of higher-value applications and explains their increased demand on accuracy of ship’s position.

1. Example navigational applications with demand on high accurate positioning and ranging

|  |  |  |  |
| --- | --- | --- | --- |
| Navigational application | Purpose of assistance or system function | Ranging approach | Positioning approach |
| Track control  (TC) | Track control systems serve the automatic steering in a variety of navigational situation ranging from sailing through narrow straits to transoceanic voyages. The demand on accurate positioning may increase up to sub-meter level if ship navigation uses the track control in areas temporary or permanently restricted by obstacles at sea or on ground. | n/a | Position-based determination of achieved position in relation to target position |
| Dynamic positioning  (DP) | A dynamic position system maintains ship’s position and heading in relation to a fixed point over ground (absolute) or to the position/attitude of a moving object (relative). | Distance measurements supporting relative DP (R4P) | Position & heading reference systems to determine difference between current and target position/movement |

R4P: Ranging for Positioning

n/a: not applicable

The use cases given in Table 1 illustrate the demands on high accurate positioning and ranging to avoid collisions and groundings. Therefore, all use cases are safety-relevant and implicate that besides accuracy the integrity of positioning and ranging has to be taken into account. In case of navigational applications (Table 2) the navigation conditions determine ultimately the demand on accuracy and integrity of needed position and range data.

# PERFOMANCE Specification

## Background

IMO Res. A.1046 (27) [5] provides recommendations on radio navigation systems and services used worldwide for ship positioning: The document specifies for general ship navigation in ocean waters that the accuracy of horizontal position should be better than 100 m with a probability of 95%. The HPA of data exchanged by the Global Maritime Distress and Safety System (GMDSS) has to be bound to 100 m. If practicable, integrity warnings should inform about the occurrence of system malfunctions, non-availability or discontinuities by future Maritime Safety Information (MSI) systems. The position error should be below 10 m with a probability of 95%, if radio navigation systems serve the determination of ship’s position in harbour entrances, harbour approaches, and costal water.

Position accuracies in the sub-meter range are required only by IMO Resolution A.915(22) [4] providing the “Revised Maritime Policy and Requirements for a Future Global Navigation Satellite System (GNSS)”. The document specifies that the absolute HPA should be better than 1 m for ship’s navigation in port areas, hydrography, cable and pipeline laying, management of aids to navigation (AtoN), and subsidence monitoring of offshore platform. The demand on increased HPA (< 0.1 m, absolute) is specified for automatic docking, constructions, and dredging. In addition hydrography, dredging and construction work are application areas needing vertical position accuracies (VPA, absolute) better than 0.1 m. For the operation of tugs, pushers, and icebreakers, the document specifies only the demand on relative position accuracy better than 1 m. Most of the previous outlined application scenarios are safety-relevant and it is necessary to evaluate and consider the integrity of provided position information. Integrity may be assumed, if the position data meets the requirements on data performance e.g. accuracy and actuality.

The threshold for tolerated inaccuracy (AL, alert limit) is always equal to the two-and-a-half times of HPA, respectively VPA. Both, the time to alarm (TTA) and the integrity risk (IR) describe requirements on the capability of integrity monitoring. Generally, the TTA (tolerated time delay between the occurrence of a significant error and its indication) should be less than 10 s in all cases. The IR (maximum permissible probability that an alert-relevant event remains undetected or unindicated) should be less than 10-5. However, the specification of performance parameters is a prerequisite for the implementation of a user-friendly integrity monitoring and the indication of monitoring results. Therefore, the Guidelines introduce structure and scale performance identifiers (see section 3.2).

The performance of systems and services enabling high-accuracy positioning or ranging should be specified in relation to the aimed results. Results at user site may be:

1. absolute position X(t)=[x, y, z, t] in a defined coordinate system;
2. relative position X(t)=[x, y, z, t] in relation to a static or dynamic reference point known in the same coordinate system;
3. distance |X(t)| in relation to a reference point or distance between 2 positions;
4. distances of ship’s hull to certain obstacles (e.g. distance to quay wall, clearance to bridge arches).

Positioning and ranging are interconnected with each other, from mathematical as well as methodical viewpoint:

* A vector is able to describe the absolute as well as the relative position of a point in the 3-dimensional space. Effectively, each vector component indicates the distances in the direction of a single axis to the origin of coordinate system (absolute position) or to a reference point in the same coordinate system (relative position). Therefore, the amount of the vector provides the distance to the origin or to the used reference point.
* For hundred of years combinations of distance and angle measurements to distinctive points (e.g. stars, lighthouse, chruch steeple) enabled the determination of relative and absolute positions. Today, modern technologies use also the interconnection between ranging and positioning as already indicated in chapter 2 by R4P (ranging for positioning) and P4R (positioning for ranging). A representative example is positioning with GNSS, where the availability of 4 or more distance measurements to GNSS satellites is the prerequisite (3D) to determine the coordinates of the unknown antenna position including the offset between GNSS receiver and system time.
* Special DGNSS services exploit relative measuring and processing techniques in signal and position domain to support high accurate positioning in their coverage area.

Therefore, it is important to achieve an umabiguous adressing of requirements (output or intermediate result) for the performance specification based on a clear meaning of used performance features (e.g. absolute, relative or statistical values).

Generally, ranging stands for a wide-variety of techniques to measure the distance between two objects or points. The techniques may use one-way or two-way runtime measurements of electromagnetic waves (radio ranging) or light waves (optical ranging). Alternatively, distance measurements may be derived from relative or absolute positioning. In both cases (R or P4R) the measuring principle as well as environmental conditions determine, if long or short distances are reliably measurable with the intended accuracy. Absolute positioning provides the position of an object in a specified coordinate system. The use case specifies ultimately the demand on position: either as point in the horizontal plane (e.g. earth surface) or as point in a 3-dimensional space (e.g. WGS84). Relative positioning provides position information of an object in relation to the position of another object (e.g. reference point, further traffic participants). Relative positioning is useful for the monitoring of ship’s navigation (e.g. own course and speed) as well as evaluation of collision risks (e.g. in relation to obstacles and other traffic participants). A general challenge on systems and services for high-accuracy positioning and ranging is the mitigation of errors induced e.g. by physical effects or atmospheric influences on signal propagation.

## Performance Considerations

The performance of systems and services proposed for high-accuracy positioning and ranging should be described unambiguously to enable users the identification of suitable solutions in relation to specific needs. Furthermore, monitoring and evaluation of operational systems and services require the specification of suitable performance criteria as well as the provision of methods for their determination. Following sections give an overview about typical performance terms and describing parameter and provide guidance for their determination and scaling.

### Performance terms and parameter

This section gives an overview about performance terms and parameter, which are typically to be used to describe needed or achieved system or data performance:

* **Accuracy,** specified by the ***probability*** that the inaccuracy of data provided is smaller than the ***error threshold***specified (e.g. horizontal position error should be below 10 m in 95% of all provided positions);
* **Actuality,** specified as tolerable ***latency*** between data surveying (time point of measuring) and providing (time point of provision or indication). Requirements on actuality may be specified indirectly by the ***update rate***, if it is assumed that the tolerable latency should be smaller than the inverse of update rate (e.g. age of corrections provided);
* **Continuity**, specified as ***probability*** that in a certain (short) ***time period*** the data provision is performed continously and meets the accuracy requirements;
* **Availability,** specified as ***percentage of time*** that in a certain (long) ***time period*** the data provision is performed and meets the accuracy requirements;
* **Update rate**, specified either by the ***fixing intervall*** (time increment between data provided succesively) or ***sampling rate*** (inverse of time increment) to define the time resolition of data determined; and
* **Coverage**, specified as specific area (e.g. ***geo-referenced parameter***, ***coordinates***) where high-accuracy positioning or ranging is needed and supported.

Typical performance parameters are typed in small caps.

Integrity stands for the ability of a system to provide users with information within a specified time when the system should not be used for navigation [4]. Therefore integrity adresses the demand on self-monitoring of performance of system operation and data provision. Requirements on integrity monitoring may be specified by:

* **Alert limit,** specified as ***Threshold of Accuracy*** to differ between fulfilled requirements on data accuracy (usability of data is given) and unfilled requirements (unusability indicated by flag or alerts);
* **Time to Alarm**, specified as tolerated ***time delay*** between occurrence of intra-system errors resulting into non-fulfillment of accuracy requirements and the indication of such events at system output; and
* **Integrity Risk**, specified as ***probability*** for a certain (short) ***time period*** tolerating that a violation of accuracy requirements remains undetected.

The data output of a system may be extended by integrity data informing about the results of integrity monitoring. The result may be (a) an estimate of accuracy or (b) the result of evaluation, if a specific alert limit has been considered. In both cases it becomes necessary to formulate additional requirements on integrity data provided at system output taking into account the applied methods of integrity monitoring as well as the alert limits of interest. This may be defined by the following terms:

* **Trustworthiness**, specified as ***probability*** for a certain (long) ***time period*** that the integrity data provided at output is correct in relation to the ***alert limit(s)*** considered;
* **Continuity (extended)**, specified as ***probability*** that in a certain (short) ***time period*** the data provision is performed continously and meets the accuracy and integrity requirements; and
* **Availability (extended)**, specified as ***percentage of time*** that in a certain (long) ***time period*** the data provision is performed and meets the accuracy and integrity requirements.

From application point of view the provision of positions or distances should be time-snychronized with the provision of associated integrity data.

### Assignment of performance parameters

Systems for high-accuracy positioning and ranging provide data products containing 3-dimensional, horizontal or vertical positions, distance vectors, or distances (see Table 3). These systems are often composed by an infrastructural system (e.g. GNSS), maybe augmentation systems (e.g. DGNSS services), and user terminals (e.g. GNSS/DGNSS receiver). The chosen system architecture determines if certain positioning and ranging techniques may be applied and, consequently, if the system can meet the performance requirements on its data output (demand on data and data quality taking into account the diversity of intended applications).

1. Prospective output data of systems for high-accuracy positioning and ranging

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| positions | | | distances | | |
| component x | horizontal | 3-dimensional | component dx | distance over ground | 3-dimensional |
| component y | component dy |
| component z | vertical | component dz | altitude,  depth, or clearance |

The performance terms and parameters listed in section 3.2.1 are sufficient to specify the requirements on system’s data output. During system development the requirements on the whole system (e.g. availability of output data or accuracy of data content) are mapped on single system components under consideration of functional responsibilities and dependencies in data flow (e.g. availability of service data or residual error in corrections). For the formulation of technical requirements on shore systems and services, the performance terms and parameters introduced in section 3.2.1 may also be used; therefore an unambiguous assignment to intermediate or final data as well as single data or data combinations should be ensured.

The fulfillment of specified performance requirments is evaluated either in real time or in relation to a specific time period. Both needs suitable key performance indicators (KPI)

* to monitor and indicate accuracy and integrity of output data in real time; and
* to validate the operational system performance for relevant time periods.

Due to the diversity of user terminals as well as the lack of knowledge regarding the current capability of the applied user terminal (e.g. disturbances, environmental conditions) it is impossible that infrastructural systems and additional services may determine the currently achieved accuracy and integrity of data output at the user terminal. At best systems and services provide estimates for accuracy and integrity achieved at system output, which are derived from KPI’s monitored itself by the system or service. The confidence level of accuracy and integrity statements depends ultimately on significance and correctness of determined KPI’s. Misinterpretation may be avoided if dependencies between used KPI, estimates of accuracy and integrity, and remaining uncertainties are clearly elaborated per output data.

Most of the performance terms and parameters described in section 3.2.1 are terms dealing with the operational performance of systems and supported functions (e.g. integrity risk, availability, continuity). They are provided in form of probability statements, whereby an unambiguous specification of them needs information about measuring periods, evaluation frame as well as evaluation conditions.

### Scaling of performance parameters

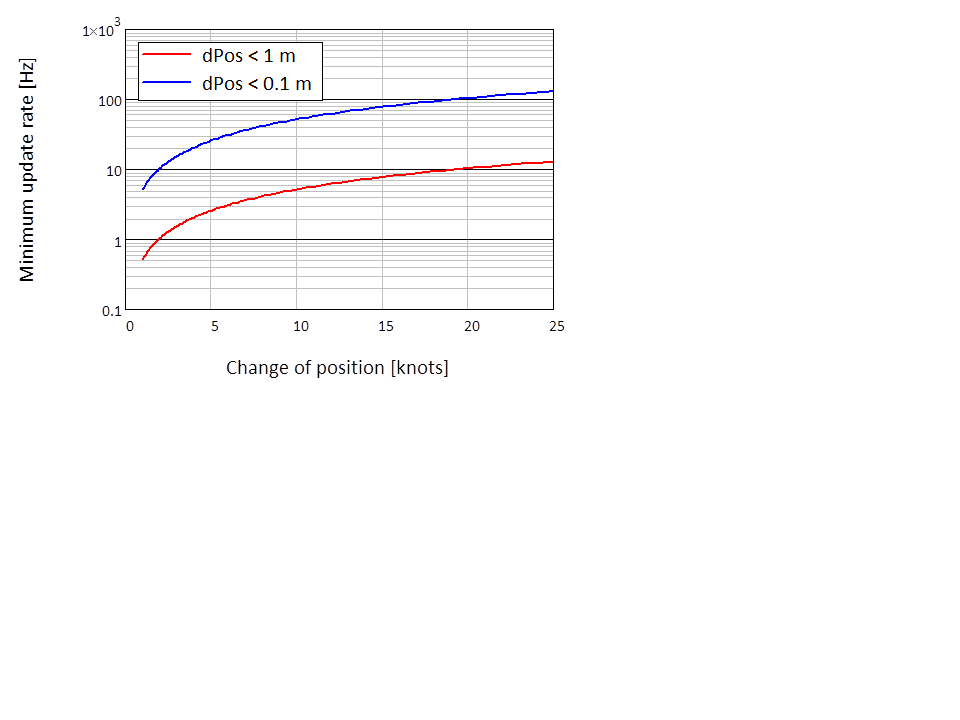
A scaling of performance requirements serves the classification and comparison of system solutions. Scaling is made on the basis of value ranges and thresholds introduced by standardisation (operational level) or by applications (technical level). Technical levels support a finer resolution of performance parameter in comparison to operational level and serve the further bidirectional harmonisation between system solutions and applications.

It has already been stated that systems for high-accuracy positioning and ranging should provide data with accuracies better than 1 m (error threshold). If accuracies are better than 0.1 m, the system falls in the category “very high accuracy”. The maritime community considers that the accuracy requirement is fulfilled if more than 95% of provided data have error below the threshold. Higher probabilities, such as shown in table 4, may be introduced to reflect further reductions of the tolerable amount of accuracy violations. Note that accuracy statements are related to the provided data (time of data availability).

1. Proposed scaling of accuracy specifications

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| error threshold  (m)  probability (%) | |  |  |  |  |  |  |  |
| operational |  | 1.0 |  |  |  | 0.1 |
| technical | 2.5 |  | 0.75 | 0.5 | 0.25 |  |
| operational | technical |  |  |  |  |  |  |  |
| 95 |  |  |  |  |  |  |  |  |
|  | 98 |  |  |  |  |  |  |  |
| 99 |  |  |  |  |  |  |  |  |
|  | 99.5 |  |  |  |  |  |  |  |
|  | 99.9 |  |  |  |  |  |  |  |
|  | 99.99 |  |  |  |  |  |  |  |

In general, the frequency interval or update rate of data provision may be the means to define the demand on actuality of provided position and range data. In case of high-accuracy positioning and ranging the actuality of data plays an increasing role. Like shown in Figure 1 the difference between current and indicated position is only below 1 m, if the update rate is higher than 2.5 Hz (assumed latency lower than 0.4 s) for ships moving with 5 knots.



1. Inaccuracies of indicated positions due to latency of information

The probability used for the description of the terms continuity and availability in section 3.2.1 is calculated as the the mean over a specific time period of data provision taking into account special performance requirements. An availability of 99.8% over 30 days may stand for an interruption of data provision taking not more than 86.4 minutes over 30 days or 2.88 minutes per day (assuming equal distribution). If the availability considers the fulfilment of a certain accuracy level, the 0.2% will be spread across times of interrupted data provision and times of degraded data provision. However, then the 95% accuracy is automatically met. Alternatively, the availability evaluation considers only service level parameter as prerequisite for accurate positioning or allows higher inaccuracies (e.g. alert limit as 2.5 times of desired accuracy).

# CLASSIFICATION OF SYSTEMS AND SERVICES

Generally, systems for high-accuracy positioning and ranging comprise several technological components to perform the diversity of functions – from measuring, via analysing to service and data provision. Several systems support especially mariner in positioning and navigation, other were deployed for general use. Representative examples of ranging and/or positioning systems are Global Navigation Satellite Systems (GNSS), Radar systems, Lidar systems, or Sonar systems. Augmentation systems provide correction and may be integrity data to the user to enable an improvement of position and distance measurements. In addition, the combined use of different systems is a typical approach to increase continuity and availability of positioning and ranging at user sites.

The following tables 5 and 6 give an overview about the wide range of systems and assigned services used for ranging and positioning in the maritime domain. It should be noted, that not all of the systems listed are able to support high-accuracy positioning or ranging. The Annexes of this guideline provide more information about techniques and methods used by individual systems to enable or support high-accuracy ranging and positioning. In addition to this, the guideline refers to the IALA NAVGUIDE [5] as the standard reference for a more detailed definition and explanation of methods, techniques, systems and services.

1. Systems enabling positioning and ranging [5]

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| System | Primary means for | Examples | Service(s) | Coverage |
| Global Navigation Satellite System (GNSS) | Positioning and timing | GPS  GLONASS  GALILEO  BEIDOU | SPS, PPS SPS, PPS OS, PRS  OS, PRS | Global |
| Regional Navigation Satellite System | Positioning and timing | QZSS |  |  |
| Long Range Navigation Systems | Positioning and timing | LORAN-C, eLORAN, CHAYKA | n.a. | Regional |
| Radar Systems | Radio detection and ranging | X-band radar S-band radar | n.a. | Local |
| Radar Beacon (RACON) | Radio detection and ranging | Lighthouses, Navigation buoys | n.a. | Local |
| Lidar systems | Light detection and ranging | Laser Ranging | n.a. | Local  (Regional) |
| Sonar | Sound detection and ranging | Active Sonar  Passive Sonar | n.a. | Local |

1. Systems supporting positioning and ranging

| System | | Primary means for | Examples | Service(s) | Coverage |
| --- | --- | --- | --- | --- | --- |
| Space Based Augmentation Systems (SBAS) |  | Provision of GNSS-related correction and integrity data | WAAS  EGNOS MSAS GAGAN SDCM | n.a. OS  n.a. n.a. n.a. | Regional |
|  |  |  |  |
| Ground Based Augmentation Systems (GBAS) – C-DGNSS | | Provision of GNSS-related correction and integrity data | IALA Beacon DGNSS | n.a. | Regional |
| Ground Based Augmentation Systems (GBAS) – RTK | | Provision of GNSS-related augmentation and integrity data | MGBAS | n.a. | Local |

# SYSTEM IMPLEMENTATION AND OPERATIONAL ASPECTS

This chapter provides guidance for the description of high-accuracy positioning and ranging systems in the annexes. Furthermore the implementation principles for harmonised system architectures of shore-based infrastructures written in IALA Guideline 1113 [6] should be taken into account.

## Shore Site Architecture

|  |  |
| --- | --- |
| Topic | Description |
| Schematic structure of the system and/or service | Block diagram and general description of all required hardware and software components |
| Data acquisition | Description of the methods for the collection of the required input data (e.g. single site approach or network based approach) |
| Data processing | Description of methods for the processing of the input data |
| Composition of data products | Description of methods for the provision of all output data |

## Transmission Services

|  |  |
| --- | --- |
| Topic | Description |
| Interfaces | Description of the required hardware interfaces between the system/service and a user device |
| Protocols and formats | Specification of the used layers, the encapsulation, and protection of data (including data security) |
| Performance parameter | Description of details concerning the aspects of operational performance specification e.g. bandwidth, latency, coverage, availability, and continuity |

## Technical Implementation

|  |  |
| --- | --- |
| Topic | Description |
| Components for the acquisition and processing of data | Detailed description concerning the installation of all system and/or service components required for data acquisition and processing |
| Components for the transmission of data | Detailed description concerning the installation of all system and/or service components required for data transmission |
| Adjustment of a measuring system | Setup of operations carried out on a measuring system so that it provides prescribed indications corresponding to given values of a quantity to be measured |

## Operational Aspects

|  |  |
| --- | --- |
| Topic | Description |
| System Performance | Details in terms of the offered Accuracy, Integrity, Continuity, Availability, Coverage of the system and/or service |
| Maintenance | Any activities (e.g. tests, measurements, replacements, adjustments and repairs) intended to retain or restore the functionality of the systems and/or service |
| Performance Verification | All activities covering the verification of the offered systems and/or service performance during the operational phase of the system and/or service |
| Publication of information | Notes on advanced information about the system and/or service (e.g. handbooks, papers etc.) |

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# ACRONYMS

|  |  |
| --- | --- |
| AL  AL | Alert Limit |
| BEIDOU | Chinese Global Navigation Satellite System |
| DGNSS | Differential GNSS |
| EGNOS | European Geostationary Navigation Overlay Service |
| FUGRO | Funderingstechniek en Grondmechanica |
| GAGAN | GPS Aided Geo Augmented Navigation |
| Galileo | European GNSS |
| GBAS | Ground Based Augmentation Service |
| GLONASS | Russian Global Navigation Satellite System |
| GMDSS | Global Maritime Distress and Safety System |
| GNSS | Global Navigation Satellite System such as GALILEO, GPS, GLONASS or BEIDOU. |
| GPS | U.S. Global Positioning System |
| HPA | Horizontal Position Accuracy (absolute) |
| HPE | Horizontal Position Error (absolute) |
| IALA | International Association of Marine Aids to Navigation and Lighthouse Authorities |
| IEC | International Electrotechnical Commission |
| IMO | International Maritime Organisation |
| IMS | Integrity Monitoring Service |
| IR | Integrity Risk |
| KPI | Key Performance Identifier |
| MGBAS | Maritime GBAS |
| MSAS | Multi-functional Satellite Augmentation System |
| MSI | Maritime Safety Information |
| P | Probability |
| P4R | Positioning for Ranging |
| PNT | Position, Navigation, and Time |
| PVT | Position, Velocity, and Time |
| PPP | Precise Point Positioning |
| R4P | Ranging for Positioning |
| RTK | Real Time Kinematic |
| SBAS | Satellite-based Augmentation System |
| SDCM | System of Differential Correction and Monitoring |
| TTA | Time to Alarm |
| VPA | Vertical Position Accuracy (absolute) |
| VPE | Vertical Position Error (absolute) |
| VRS | Virtual Reference Station |
| WAAS | Wide Area Augmentation System |
| WWRNS | World Wide Radio Navigation Systems  aaa |

# Appendix: Definitions

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| Accuracy | Accuracy is the degree of conformance between the estimated or measured parameter at a given time and its true parameter at that time.  *Comment:*   * *Parameters in these Guidelines may be distance measurements, positions, error estimates as well as performa*nce identifier*s.* |
| Accuracy - absolute | Absolute accuracy means, that the estimated parameter accuracy is determined in the same reference system.  *Comment:*   * *Absolute position accuracies should be determined with respect to the used geographic or geodetic coordinate system of the Earth.* |
| Accuracy -  relative | Relative accuracy is the accuracy of a difference between 2 parameters measured or determined at the same time with different methods or systems.  *Comment:*   * *Relative position accuracy means the user is determining the position relative to that of another user or reference objects at the same time and in the same coordinate system.* |
| Alert Limit | In case of integrity monitoring the maximum allowable error in the measured parameter before an alarm should be triggered. |
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| Availability - System | The percentage of time that a system is performing a required function or set of functions under stated conditions in a specified interval of time. |
| Availability -  Data | The percentage of time that data is provided in a specified interval of time with the specified performance and update rate. |
| Availability -  Signal | The percentage of time that the signal may be received in the coverage area in a specified interval of time. |
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| Continuity | The probability thata system, service, or function works interruption-free with the specified performance over the required (short) time interval. |
| Continuity of positioning | The probability that, assuming a fault-free receiver, a user will be able to determine position with specified accuracy and is able to monitor the integrity of the determined position over the (short) time interval applicable for a particular operation within a limited part of the coverage area. |
| Coverage | The coverage is the surface area or space volume in which the signals of a system or service are adequate to permit their use with the specified level of performance. |
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| Integrity | The ability to provide users with information within a specified time when the system should not be used for navigation including measures and/or indicating of trust. |
| Integrity risk | The probability that a user will experience a parameter with an inaccuracy larger than the defined alert limit without an alarm being raised within the specified time to alarm. |
| Latency | Latency is the time lag between parameter observation and provision or indication. |
| Precision | Precision describes the uncertainty of a parameter with respect to impact of random errors. |
| Resilience | Resilience is the ability of a system to detect and compensate external and internal disturbances, malfunction and breakdowns in parts of the system. This should be achieved without loss of functionalities and preferably without degradation of their performance. |
| Time to alarm | The time elapsed between the occurrence of a failure in the system and its indication. |
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| Update rate | Update rate specifies the rate at which parameters should be re-measured, re-calculated or re-provided. |
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1. PERFORMANCE AND MONITORING OF MARITIME GROUND BASED AUGMENTATION SYSTEMS (MGBAS) FOR HIGH-ACCURACY POSITIONING IN PORTS
2. INTRODUCTION

This Annex to the Guideline ‘Systems and services for high-accuracy positioning and ranging’ provides the design and implementation principles of Maritime Ground Based Augmentation Systems usable in a port/harbour environment for high-accurate absolute and/or relative positioning. High-accurate positioning means that the absolute and/or relative position accuracy (95%) is 0.1 m or better.

* 1. Scope of document

Global Navigation Satellite Systems (GNSS) are space-based systems providing navigation signals and information, whose use enables world-wide the determination of positioning, navigation and time data. GPS and GLONASS are the first GNSS available. Modernised GNSS include enhanced GPS and GLONASS along with new core constellations such as Galileo and BeiDou.

Differential GNSS (DGNSS) are means to provide augmentation services to improve the accuracy of GNSS-based positioning and to monitor the integrity. DGNSS involves having reference stations, at precisely known locations that provide real-time corrections and integrity information for GNSS signals. Therefore, DGNSS is not a stand-alone radio navigation system. DGNSS systems provide shore-to-ship services.

This existing IALA Guideline 1112 on Performance and Monitoring of DGNSS Services in the Frequency Band 283.5-325kHz describes the generation and broadcast of code based corrections with a focus on the maritime domain. The application of code-based DGNSS services enables that position accuracies of few meters up to few decimeters can be achieved depending on distance between reference site and user. IALA Recommendation R-135 on Future of DGNSS is introducing alternative technologies such as Real Time Kinematic (RTK) under consideration of technical progress of last decades. RTK has been identified as service supporting the application of phase-based differential positioning algorithm to achieve position accuracy of 0.1 m or better.

Neither GNSS nor DGNSS do inherently provide integrity information. However, code-based as well as phase-based DGNSS services are in the position to provide also integrity information in relation to used GNSS and provided DGNSS service. System failures as well as disturbances can result into significant errors for extended periods of time, without notifying the user. Maritime augmentation services should provide the user with integrity information to support the situation awareness of mariners in relation to current reliability and usability of applied navigation aids. The service provider should publish that they follow IMO and IALA Recommendations for the provision of DGNSS services, giving emphasis to the provision of integrity information. In addition to these Guidelines the following recommendations from IALA should be taken into account:

* Future DGNSS options are captured in R-135 [2]
* Vulnerability of GNSS systems is discussed in R-129 [3]
* Recommendation to National Members to provide DGNSS is captured in R-115 [4]
* IEC61108-4
  1. Structure of document

Chapter 2 “*Shore site architecture”* covers the topics schematic structure of the system and/or service, data acquisition, data processing, and composition of data products.

Chapter 3 “*Transmission services”* covers the topics interfaces, protocols and formats, and performance parameter.

Chapter 4 “*Technical implementation”* covers the topics components for the acquisition and processing of data, components for the transmission of data, and adjustment of a measuring system.

Chapter 5 “*Operational Aspects”* covers the topics system performance, maintenance, performance verification, and publication of information.

Appendices include various technical settings for evaluation and indication of GNSS and DGNSS status and integrity. The following appendices are included:

• Appendix A: Technical settings for GNSS and DGNSS evaluation

• Appendix B: Technical settings for integrity indication

• Appendix C: Acronyms, which are not listed in main document

1. PERFORMANCE REQUIREMENTS
   1. Definitions

System performance is characterized by a number of different aspects, including Accuracy, Integrity, Continuity, Availability and Coverage as defined in [2].

* 1. Positioning Performance Requirements

IMO Resolution A.1046 (27) details the minimum requirements on worldwide radio navigation systems considering vessels operating in ocean and harbour entrances, harbour approaches and coastal waters. The requirements are described by accuracy, integrity, availability, and continuity for positioning……

1. Performance levels of RTK services enabling high-accurate positioning in harbours

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RTK Service providers should consider the appropriate number, and location, of reference stations to achieve sufficient coverage to ensure that these requirements are met in selected and/or complete harbour areas.

1. SHORE SITE ARCHITECTURE

This chapter deals with the shore site architecture of phase-based DGNSS services and follows the generalized DGNSS architecture introduced by [2]. Therefore, a phase-based DGNSS is composed by 2 subsystems:

* subsystem for the generation of GNSS augmentation service and
* the subsystem realizing the transmission service.
  1. Structure of system and service
  2. GNSS Data Acquisition

This sections deals with the provision of GNSS range measurements and navigation messages for the MGBAS phase-based DGNSS data processing. It follows the generalized description in [2].

* + 1. Single site Approach

See description of classic approach for GNSS data acquisition in [2].

* + 1. Network based Approach

See description of network based approach for GNSS data acquisition in [2].

* 1. GNSS Data Processing
* Following the generalized scheme of Figure 3 “Stages of GNSS data processing during service provision” in [2]
* RS: generation of a set of proven multi-frequency GNSS phase measurements for supported GNSS with integrity information
* IM: Assessment of provided phase measurements and integrity information of RS together with own phase measurement (signal and position domain)
  1. Composition of Service data products
* Phase measurements RTCM3
* Integrity Information proposal RTCM3 message 4083
* Data rate
* Position of real or virtual reference station

1. Transmission Services

* Radio transmission in UHF band (447.95 MHz for Germany)
* NTRIP broadcast over Internet
  1. Interfaces
* Radio transmission in UHF band with suggested 38400 bps
* NTRIP server at station or other information distribution server with good network connectivity
  1. Protocols and formats
* Using RTCM3 messages for phase measurements and integrity message 4083
* Description of 4083
* NTRIP for provision over Internet
  1. Performance Aspects
     1. Latency
* Sum of delays from signal measurement, data distribution, data processing, coding and messages broadcast using UHF and Internet
* Delay aspects of Internet transmission
  + 1. Range and Coverage Aspects
* Usability of phase-based corrections limited on few 10 km
* Local data provision with UHF depending on transmitting power
* Using Internet unlimited coverage as long as service internet ports of NTRIP server are reachable
  + 1. Availability
* Radio transmission service: see 3.2.5.3 of [2]
* Availability aspects using Internet
  + 1. Continuity
* Adaptation of 3.2.5.4 of [2] on both transmission channels
  + 1. Monitoring of transmission

1. Technical Implementation

* Following the general technical implementation in [2] with exception of the two transmission channels for MGBAS

1. Implementation of a phase-based DGNSS service taking into account supported transmission
   1. Components of GNSS augmentation services
      1. Reference Station

* Single side approach: equipped with GNSS receiver, GNSS antenna with multipath reduction, data processing unit, and data transmission unit
* Network approach: no reference station at reference position necessary; transmitter in the vicinity of station coordinates when using UHF
  + 1. Monitoring Stations
* Adaptation of 3.3.1 in [2]
  + 1. Communications
* Communication between reference and monitoring station over network (specify protocol)
  1. Components for the Transmission of data
     1. Transmitter
     2. Transmission Monitors
     3. Communications
  2. Adjustment of a measuring system

1. OPERATIONAL ASPECTS
   1. System Performance
      1. Accuracy Aspects

* Adaptation of 3.1.4.1 in [2]
  + 1. Integrity Aspects
* Adaptation of 3.1.4.2 in [2]
  + 1. Availability Aspects
* Adaptation of 3.1.4.3 in [2]
  + 1. Continuity Aspects

See section 3.1.4.4, continuity aspects, in [2].

* 1. Operation and Maintenance

See general description about Operation and maintenance in [2].

* 1. Performance Verification
     1. Availability in the coverage area
* Adaptation of 4.2.1 in [2]
  + 1. Continuity
* Adaptation of 4.2.2 in [2]
  + 1. Verification of integrity monitoring
* Adaptation of 4.2.3 in [2]
  + 1. Verification of Accuracy
* Adaptation of 4.2.4 in [2]
  1. Publication of information
* Adaptation of 4.3 in [2]

1. APPENDIX A: Technical settings for GNSS and DGNSS evaluation
2. APPENDIX b: Technical settings for integrity indication
3. Appendix C: Acornyms

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